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TECHNIQUES FOR REDUCING GUN BLAST NOISE LEVELS: AN EXPERIMENTAL STUDY

by
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APRIL 1981

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Several techniques for reducing gun muzzle blast noise level were investigated experimentally to determine potential effectiveness and utility for existing major-caliber guns. Techniques explored included muzzle brakes, conical muzzle devices, baffle-type silencers, water spray, and aqueous foam.

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FOREWORD

This report was prepared as part of a developmental program to determine methods of reducing noise levels due to Naval weapons, particularly large guns, during training and testing operations. Early work was funded by the Naval Science Assistance Program (NSAP) at the request of COMTHIRDFLT and by the Navy Independent Research program. The majority of work was carried out under the Gun Blast Effects program, NAVSEATASK 653/497/004-1-S0956.

This report was reviewed and approved by F. H. Maillie and J. F. Horton of the Systems Safety Division of the Combat Systems Department.

Released by:

Thomas A. Clare

THOMAS A. CLARE, Head
Combat Systems Department

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TABLES

ABBREVIATIONS AND ACRONYMS

BM	Barrel Muzzle
caliber	1.0 barrel bore diameter
dB	Decibel
GPM	Gallons per Minute
Hz	Hertz
kn	Knots
mm	Millimeter
No.	Number
NSAP	Naval Science Assistance Program
psi	Pounds per square inch
PSPL	Peak Sound Pressure Level

INTRODUCTION

OBJECTIVE

The purpose of this project was to determine the utility and effectiveness of several techniques for reducing gun blast far-field noise. The techniques that were investigated are in general applicable to guns of all sizes, from pistols and rifles to very large artillery and naval guns. Primary interest was in procedures and/or devices suitable for use on major-caliber guns such as the 5"/54 naval gun. It was desired that the procedures or devices be suitable for temporary use (e.g., during training and testing operations) on existing gun systems, without requiring extensive modification of, or causing damage to, the gun system or platform. Only a negligible effect on projectile trajectory could be tolerated, and impact on training and testing operations was to be minimized.

Most of the noise reduction techniques that were investigated involve the use of some type of muzzle device. The requirement that the noise reducing device be suitable for use on existing gun systems severely restricts the allowable size and weight of the device. For example, very effective silencers have been developed for pistols and rifles, but these devices are typically of about the same size and weight as the gun barrel, and thus are obviously not suitable for use on major-caliber guns. Hardware size and weight restrictions were thus a major consideration throughout the project.

BACKGROUND

There are three sources of noise associated with firing a gun. These are the muzzle blast that occurs when the projectile uncorks the high-pressure propellant gases, the bow shock (sonic boom) of the supersonic projectile, and projectile detonation. Projectile detonation noise can be eliminated or reduced by using projectiles that are inert or contain only a very small spotting charge. The projectile bow shock noise field is discussed in some detail in another report[1] and will be discussed only briefly here. Projectile bow shock exists in only a portion of the blast field, typically within a sector of about 60° to either side of the line of fire. Within this region, bow shock noise level at the earth's surface varies according to a complicated dependence upon projectile trajectory, projectile speed along the trajectory, projectile size and shape, and atmospheric acoustic refraction. The bow shock noise may be more significant than muzzle blast noise at some field locations, especially near the line of fire. Noise exposure due to projectile bow shock can be minimized by stopping the projectile at the shortest possible range. It should be noted that a muzzle blast noise reduction technique that has no effect on the projectile velocity or trajectory will have no effect on the projectile bow shock noise field.

Reducing muzzle blast noise is a challenging problem, since muzzle blast is an unavoidable effect of firing a gun. One approach is to use "no-fire simulation" in lieu of firing for training purposes. This technique involves training disadvantages and requires sophisticated and expensive simulation systems, and so may reduce but probably not eliminate gunfire for training, and would have only limited application for testing.

Under the proviso that the gun is to actually be fired, there are basically two approaches to reducing muzzle blast noise:

1. Redistribute the blast field energy such that noise levels are decreased in some regions of the blast field, at the expense of increased noise levels in other regions.

2. Remove energy from the blast wave, resulting in decreased sound levels throughout the entire blast field.

There are several potential methods of implementing these two basic approaches. Naturally occurring atmospheric sound refraction can be used (but not controlled) to redistribute blast field energy. This technique can be important for all types of noise and has been extensively discussed in other reports.[2-10] Methods of implementing utilization of atmospheric refraction include field monitoring of noise levels and ray-tracing algorithms based on meteorological sounding data. Cognizance of atmospheric refraction must be a mandatory part of noise control procedures for far-field explosive noise, since the phenomenon can result in result in noise level variations of as much as 50 dB for a given source.

A blast energy redistribution technique that offers more direct control of gun muzzle blast noise levels is utilization of muzzle blast field directivity. Recent studies[1,11] have shown that muzzle blast directivity amounts to approximately 15 dB throughout the far field; i.e., the peak sound pressure level (PSPL) and C-weighted sound exposure level at a given distance from the gun are about 15 dB higher in front of the gun than behind the gun. Thus, in some firing range scenarios, a measure of control of noise levels can be achieved by controlling direction of fire as well as gun location.

PROJECT SCOPE

The current project consisted of further investigation of techniques and devices for controlling gun muzzle blast noise levels. Conical muzzle devices and a muzzle brake were tested to determine the degree of blast redistribution due to such devices. Blast reducers of conventional silencer design, but small and light enough to possibly be used with existing major-caliber guns, were investigated as a method of removing energy from the blast wave. Another technique for removing energy from the blast wave, which was investigated in a preliminary fashion, was to introduce into the gun muzzle region some substance that would interact with and remove energy from the blast wave during or shortly after its formation. Substances that were tried included water spray and aqueous foam.

The effectiveness of each noise reduction technique was judged according to the amount of reduction in PSPL that was achieved.* It is generally agreed that, for occasional noise events, unaided human hearing cannot reliably detect differences in PSPL smaller than about 3 dB. On the other hand, a change of 10 dB

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* It should be recognized that PSPL alone is not necessarily an adequate general description of human annoyance.[10,12,13,14,15] However, PSPL is a good indicator if duration and spectral energy distribution are not greatly changed, and offers the advantage of being easily measured.

seems to correspond roughly to a factor of two change in subjective noisiness or annoyance. Thus, any noise reduction technique that yields a change in noise level of less than 3 dB is of little or no value in terms of reducing human annoyance. A reduction of at least 10 dB was the goal of the present project.

BASELINE: BARE MUZZLE

The near-field peak overpressure distribution for bare muzzle guns has been extensively documented.[16-22] Figure 1 shows a typical near-field peak overpressure distribution.[17*] Figure 2 shows the same blast field expressed as PSPL in units of decibels,** and Figure 3 explicitly shows the PSPL directivity relative to 180° from the line of fire. This same near-field directivity information is shown in different format in Figure 4. Also shown in Figure 4 is near-field data for the 7.62-mm rifle used to obtain most of the data presented in this report. It can be seen that the 7.62-mm rifle near-field peak overpressure directivity agrees quite well with that of major-caliber naval guns. The general validity of reduced-scale investigation of near-field gun muzzle blast has been well established.[1,16,17,18,23]

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* This blast field is an average for a wide variety of naval guns. Similitude was achieved by expressing radial distance from the gun muzzle in units of calibers, one caliber being equal to the gun bore diameter.

** Peak sound pressure level (PSPL, or L_{pk}) is a logarithmic comparison scale defined by

$$L_{pk} = 10 \log_{10} \left(\frac{P_m}{P_o}\right)^2 = 20 \log_{10} \frac{P_m}{P_o}$$

in units of decibels, where P_m = peak overpressure and $P_o = 20\ \mu P_a = 2.9 \times 10^{-9}$ psi = reference overpressure for 0 dB. Further discussion may be found in many references, for example Reference 1 or 10 of this report.

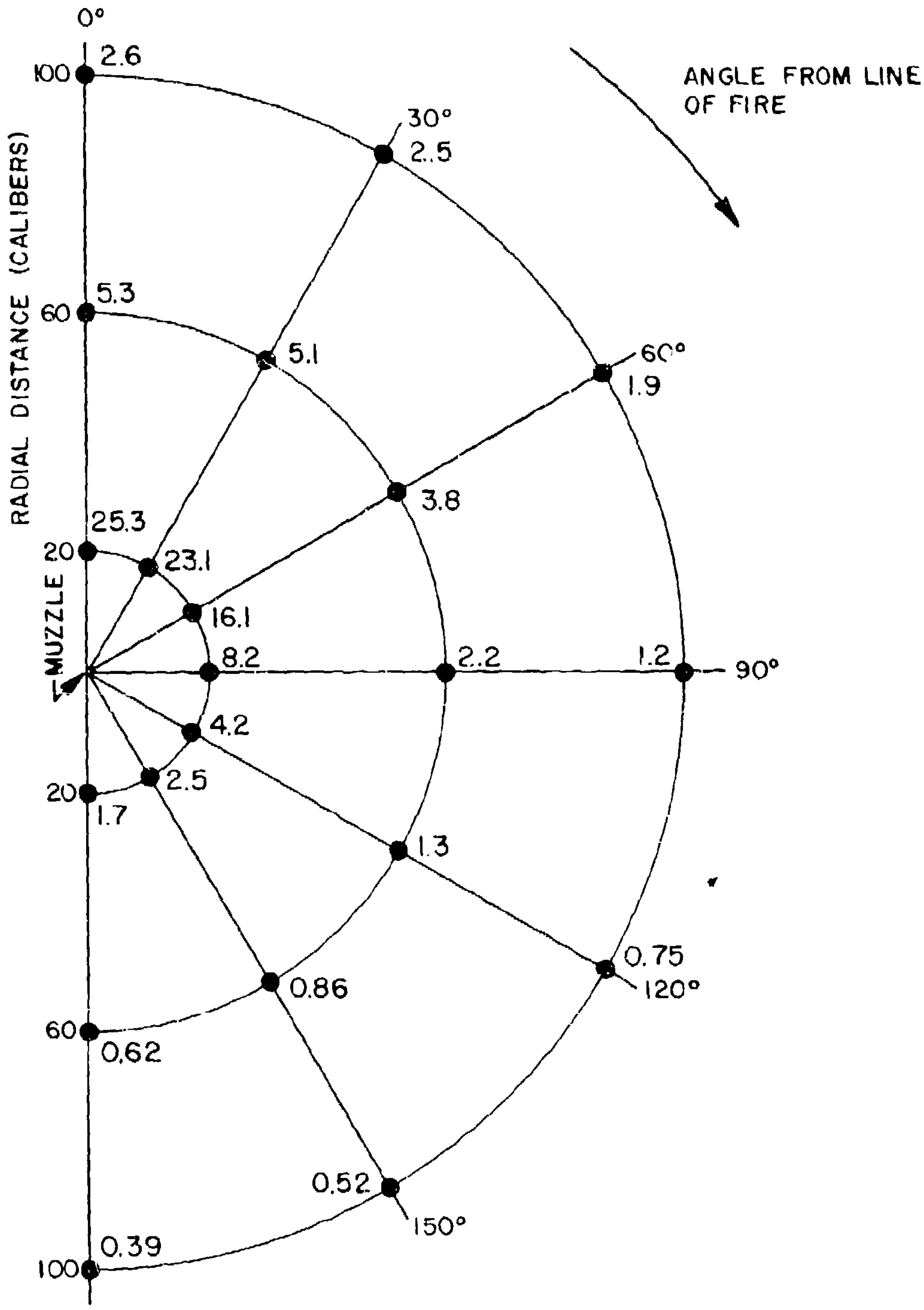

Figure 1. Bare Muzzle Near-Field Peak Overpressure (psi)

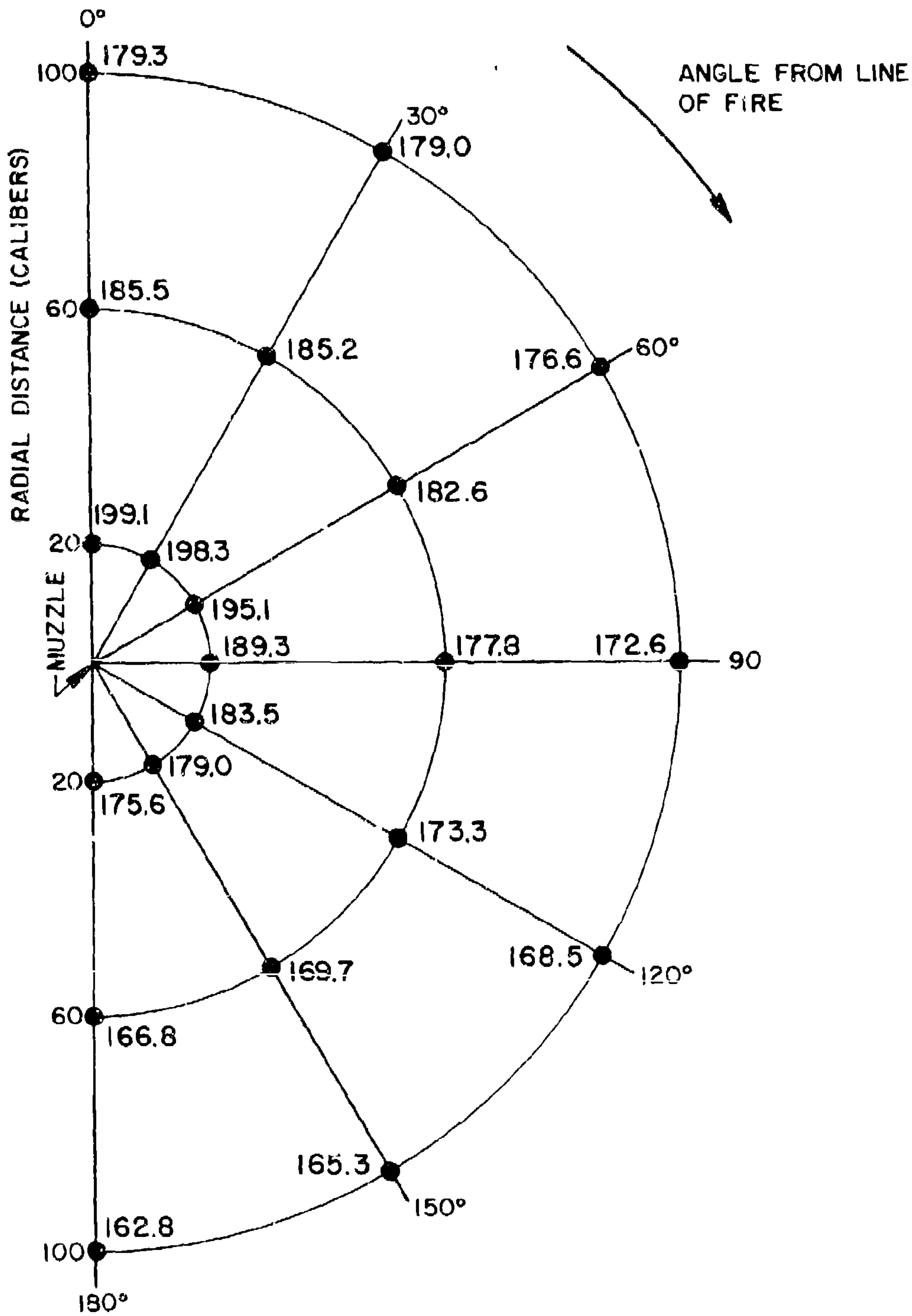

Figure 2. Bare Muzzle Near-Field Peak Sound Pressure Level (dB)

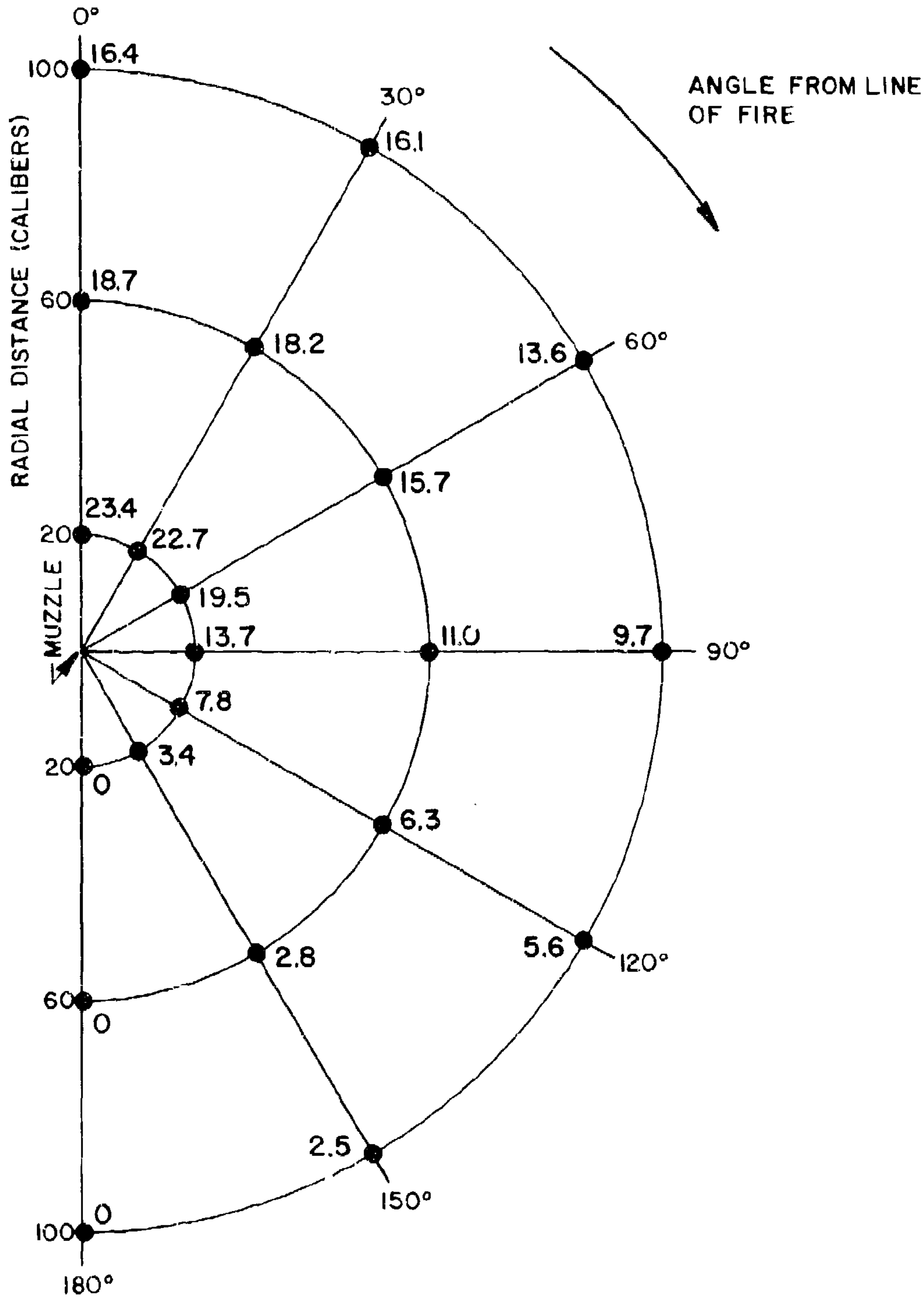

Figure 3. Bare Muzzle Near-Field Directivity (dB) re 180°

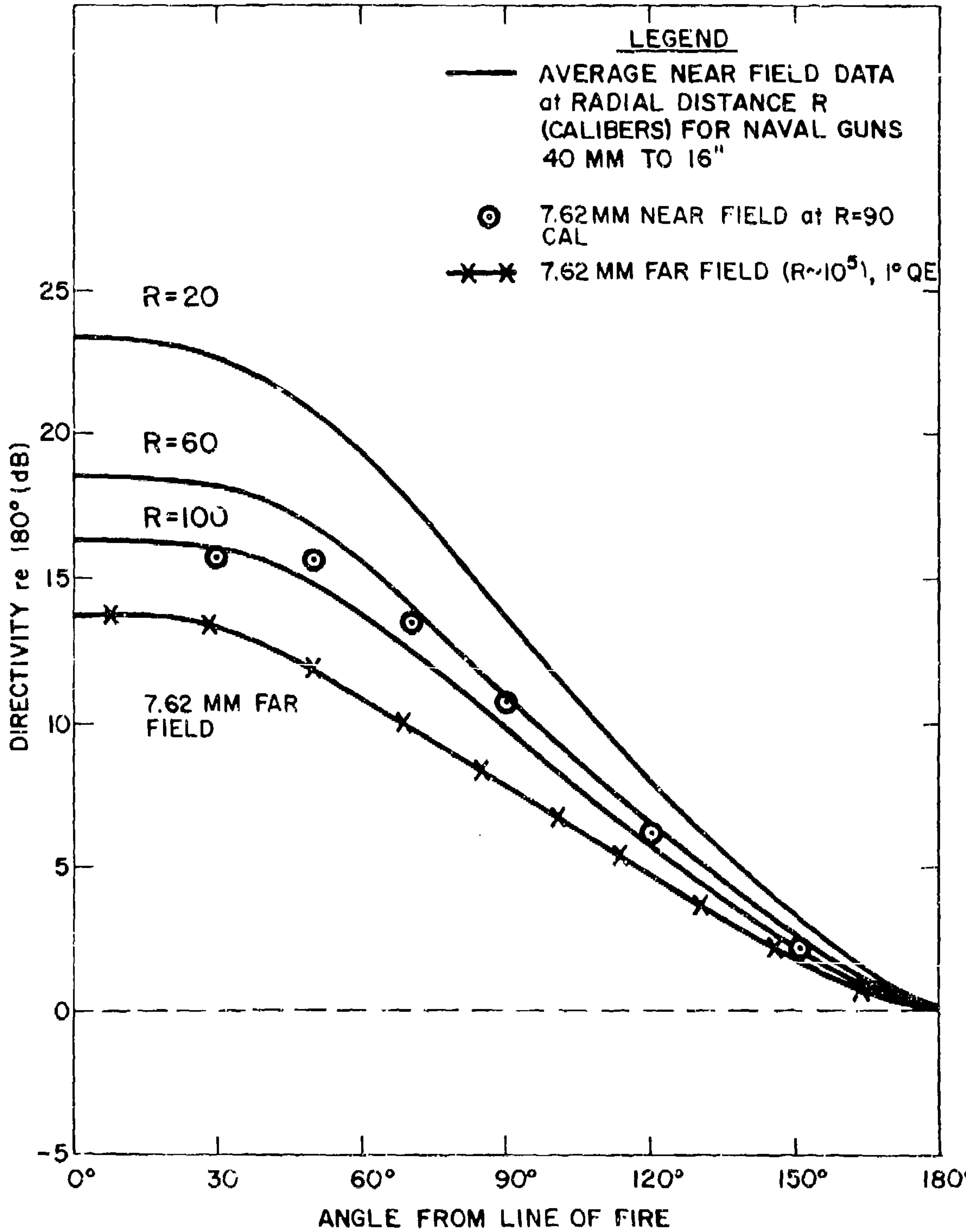

Figure 4. Muzzle Blast Directivity

Recent work[1,11] has shown that gun muzzle blast PSPL directivity amounts to about 14 to 17 dB and is essentially constant for a given gun throughout the far field.* The far-field PSPL directivity of the 7.62-mm rifle used in the present investigation is shown in Figure 4. It has been shown[1] that the 7.62-mm rifle is an adequate scale replica of major-caliber guns for purposes of reduced-scale blast field investigation.

PROCEDURES AND APPARATUS

The noise parameter that was measured throughout the current study was peak unweighted sound pressure level. Data acquisition was by means of Gen Rad Model 1982 sound level meters. For measurement of PSPL, the meter control settings used were "flat" weighting, "peak" detector, octave filter selector set to "WTG" (broad band), and the range switch set to the appropriate decibel range. Microphone attenuators (-10 dB) were used when PSPL exceeded 140 dB. The meters were modified to make the PSPL value available as a constant voltage at the "DC out" jack, output linear in decibel. This voltage was transmitted via land lines, using a specially fabricated "line driver," from each instrumentation location to an instrumentation van where the voltage values were sequentially and rapidly recorded by means of a Datel Systems Model PDL-10 Data Logger. The recorded voltages were converted to decibel values during data reduction by means of voltage versus decibel calibration curves previously prepared for each sound level meter. The meters were also modified by installation of a small solenoid used to remotely actuate (from the instrumentation van) reset of the peak and hold circuitry. Sound level meters were calibrated before each test by means of Gen Rad Model 1567 1000 Hz Sound Level Calibrators.

The 7.62-mm rifles used to obtain most of the data were mounted in an over-and-under configuration on a machine gun tripod as shown in Figure 5. This

* Data have been presented for distances in excess of 100,000 calibers.

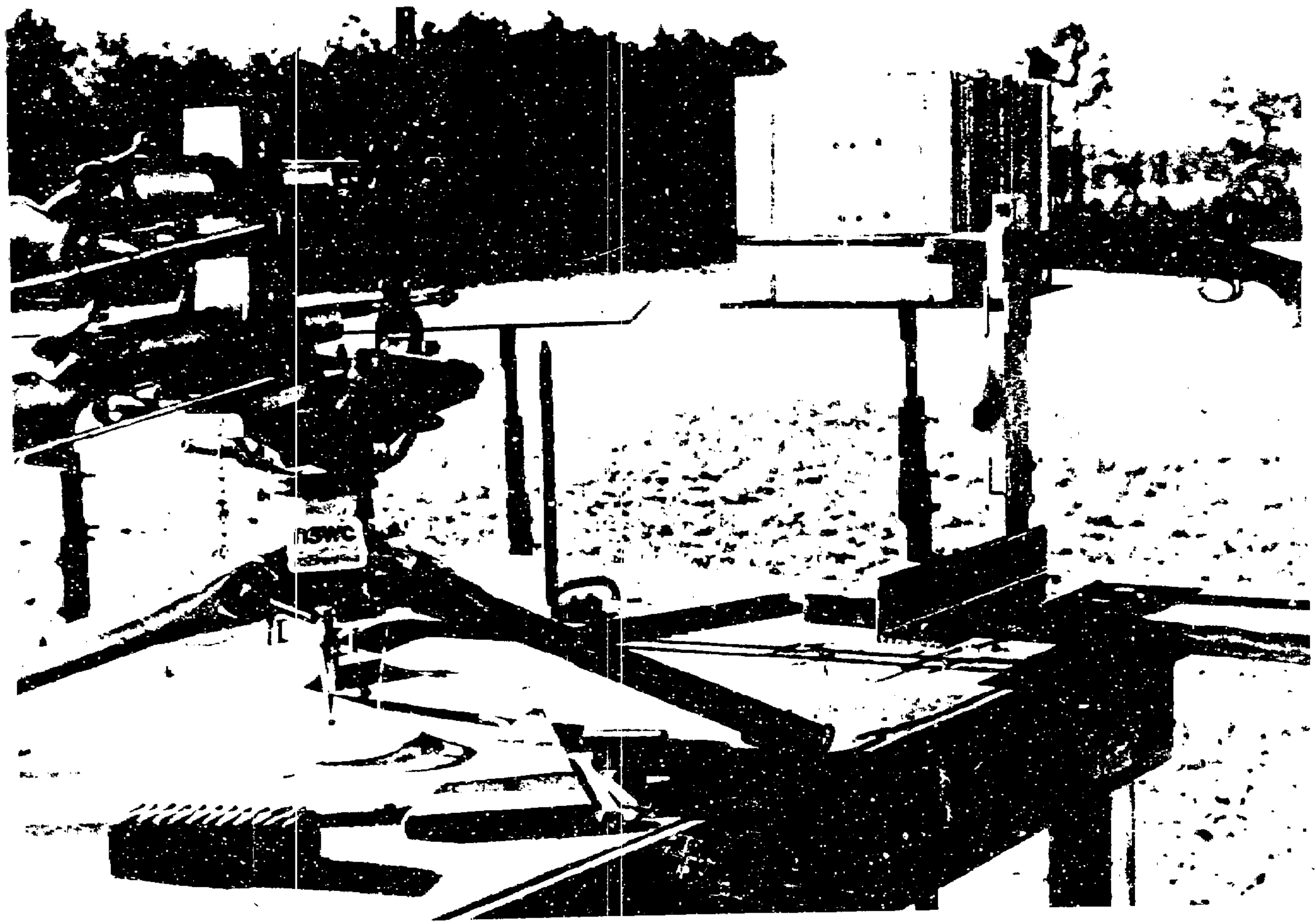

Figure 5. 7.62-mm Rifles

arrangement allowed accurate and repeatable adjustments of gun train angle (direction of fire), so that data could be obtained at various angles from the line of fire without moving the instrumentation. Projectile bow shock was eliminated from the blast field by means of bullet traps located a few hundred calibers downrange from the gun muzzle.

Throughout this report the effects of the various muzzle blast noise reduction techniques are presented in terms of excursions of far-field PSPL from the far-field directivity curve* shown in Figure 4. This data presentation is meaningful since both far-field directivity and the effect of each noise reduction technique relative to the directivity curve are practically invarient throughout the far-field, except for variations caused by atmospheric refraction. Atmospheric refraction effects on the data were avoided to a considerable extent by using two closely juxtaposed guns, one bare muzzle and one employing the noise reduction technique. The guns were fired at about 10-second time intervals, with a total of six rounds fired from each gun at each train angle of interest, for most of the tests. The parameter of interest is the difference in noise level for the two guns. This procedure relies on the assumption that atmospheric propagation conditions do not vary significantly during a short time interval, which is generally true for gross atmospheric temperature and wind structure. Wind gusts or atmospheric turbulence can, nevertheless, result in significant data scatter. Nearly all testing was conducted at night to take advantage of relatively stable atmospheric propagation conditions and minimal winds. Data scatter was further minimized by using ammunition from a single specially selected production lot. Further details of the test apparatus and procedures, including some aspects not of importance to the results presented in this report, may be found in Reference 1.

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* These results may be translated into absolute levels through use of available models[1,11] for bare muzzle far-field gun blast, expressed as a function of distance from the gun, angle from the direction of fire, and gun elevation angle for various atmospheric propagation conditions.

MUZZLE BRAKE

The far-field PSPL distribution of a muzzle brake was measured using the 7.62-mm rifle and procedures described above. The muzzle brake was a conventional (open sides, flat top and bottom plates) single baffle design of 1.25 calibers inside length, 2 calibers inside height, 3 calibers wide flat baffle, momentum index ≅1.2.* Far-field PSPL measurements were made at distances from the gun muzzle and angles from the line of fire shown in Table 1.

The data shown in Table 1 exhibit effects of atmospheric refraction. These effects can be removed to a considerable extent, as discussed under "PROCEDURES AND APPARATUS," by examining the difference between PSPL values with and without the muzzle brake. These values, shown in Table 2, show the effect of the muzzle brake. It can be seen that, within the uncertainty limits of data scatter, the far-field effect of the muzzle brake on PSPL is essentially independent of distance in the far field.

The averaged (for all four measurement distances) effect of the muzzle brake, from Table 2, is shown in Figure 6 as excursions from the bare muzzle directivity curve. The significance of the ±3 dB bounding curves (dashed lines) is that data points that fall between the bounding curves represent an insigificant noise level change in terms of human perception of noisiness. It can be seen from Figure 6 that the only <u>significant</u> change in PSPL caused by the muzzle brake was an increase, in the region behind the gun.** The tested muzzle brake and its blast field are quite typical of practical muzzle brakes. Hence, it can be concluded that muzzle brakes are of little use for reducing far-field noise disturbance.

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* This muzzle brake is configuration No. 1 of Reference 24, geometrically scaled according to gun caliber (bore diameter).

** It is interesting to note that near-field directivity[24] is preserved to some extent into the far field, as is the case for bare muzzle directivity[1] as illustrated in Figure 4.

Table 1. Muzzle Brake Far-Field PSPL Raw Data, 7.62-mm Rifle

Angle from Direction of Fire (degrees)	Peak Sound Pressure Level (dB) @ R (calibers)							
	14,000		26,000		80,200		138,000	
	Bare Muzzle	Muzzle Brake	Bare Muzzle	Muzzle Brake	Bare Muzzle	Muzzle Brake	Bare Muzzle	Muzzle Brake
10	121.1	118.0	114.1	110.8	100.7	97.8	86.9	83.9
30	123.3	120.9	115.6	115.2	101.9	99.1	88.6	86.1
50	121.1	119.6	112.9	113.4	99.1	97.0	84.8	82.3
70	116.4	115.8	110.5	108.4	94.4	94.5	78.1	75.6
90	116.6	116.8	110.2	110.0	94.4	95.2	78.9	78.2
120	114.6	117.6	106.1	109.2	93.4	99.2	77.3	83.7
150	110.5	115.8	102.6	107.8	87.9	95.7	73.9	82.0
180	109.0	115.6	105.4	110.9	89.0	94.5	73.9	80.1

Table 2. Change in Far-Field PSPL Due to Muzzle Brake, 7.62-mm Rifle

Angle from Direction of Fire (degrees)	Δ PSPL (dB) @ R (calibers)				
	14,000	26,000	80,200	138,000	All (mean)
10	-3.1	-3.3	-2.9	-3.0	-3.1
30	-2.4	-0.4	-2.8	-2.5	-2.0
50	-1.5	+0.5	-2.1	-2.5	-1.4
70	-0.6	-2.1	+0.1	-2.5	-1.3
90	+0.2	-0.2	+0.8	-0.7	0.0
120	+3.0	+3.1	+5.8	+6.4	+4.6
150	+5.3	+5.2	+7.8	+8.1	+6.6
180	+6.6	+5.5	+5.5	+6.2	+6.0

CONICAL MUZZLE DEVICES

The effects of conical muzzle devices on near-field gun blast have been reported previously,[16,25,26,27] and some data regarding the effect on recoil impulse is also available.[27] In general, the effects are increased peak overpressure in front of the gun and in the remainder of the blast field, especially behind the muzzle, and some decrease in peak overpressure. This amounts to enhancement of the bare muzzle directivity. Also, there is some increase in recoil impulse.

The near-field blast study of SooHoo and Yagla[26] presents typical near-field conical muzzle device results, obtained using the 5"/54 naval gun. Peak overpressure data were presented for the bare muzzle gun and for a conical muzzle

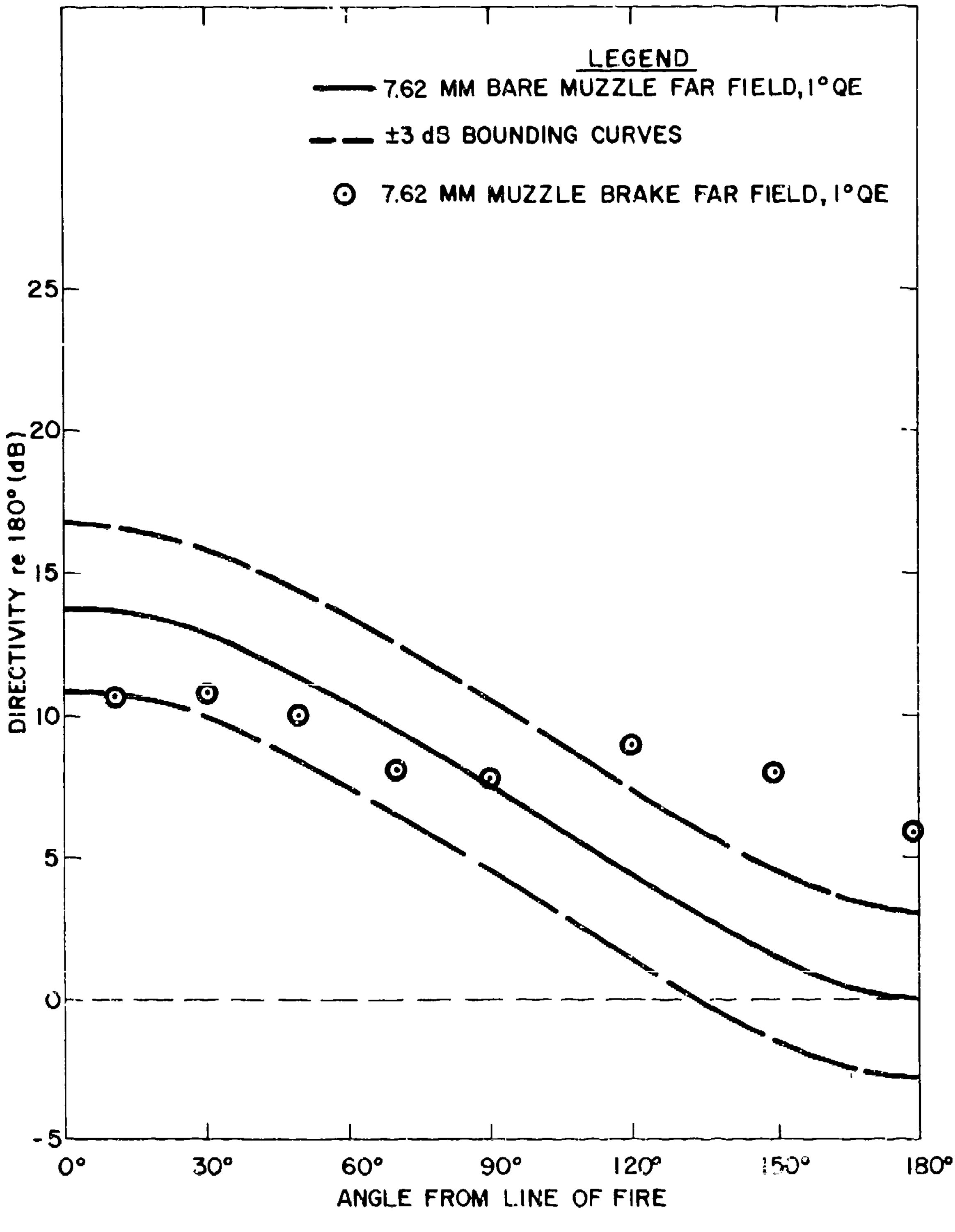

Figure 6. Change in Muzzle Blast Far-Field PSPL Due to Muzzle Brake

device of 10° half-angle, 4.2 calibers in length, and with an initial inside diameter of 1.05 calibers. Results are presented in Figure 7* in terms of the change in PSPL due to the muzzle device. These results are quite typical of a rather wide range of muzzle devices,[27] including cones, cylinders, and paraboloids of various sizes. It can be seen that the increase in directivity is substantial in the near field, but decreases with increasing distance from the muzzle.

Far-field effects on muzzle blast PSPL were obtained during the present study for a conical muzzle device of 10° half-angle, with an inside length of 4.0 calibers and an initial inside diameter of 1.1 calibers. This muzzle device is nearly a scale replica of the device of SooHoo and Yagla[26] discussed above. Data were obtained using the 7.62-mm rifle and test apparatus described earlier. Results are presented in Tables 3 and 4 and in Figures 7 and 8. Figure 7 shows the change in far-field PSPL explicitly, and Figure 8 shows the excursion from the bare muzzle directivity curve.

A preliminary investigation[28] of the effect of a conical muzzle device on far-field muzzle blast also provided some data. The basic philosophy of the experiment was quite similar to the 7.62-mm rifle tests; differences included the guns (5"/54), firing interval, instrumentation locations, and that the guns were fired on a fixed direction of fire, with field measurement locations varied by moving the instrumentation. The two guns, located about 120 calibers apart, were fired within about 30 seconds. One of the guns was equipped with a 10° conical muzzle device identical to that used by SooHoo and Yagla.[26] The test was fired during daylight hours, under quite significant atmospheric refraction conditions, with the result that no data were obtained at some of the desired field points

* The results for angles near 180° may be strongly influenced by the presence of the gun mount.

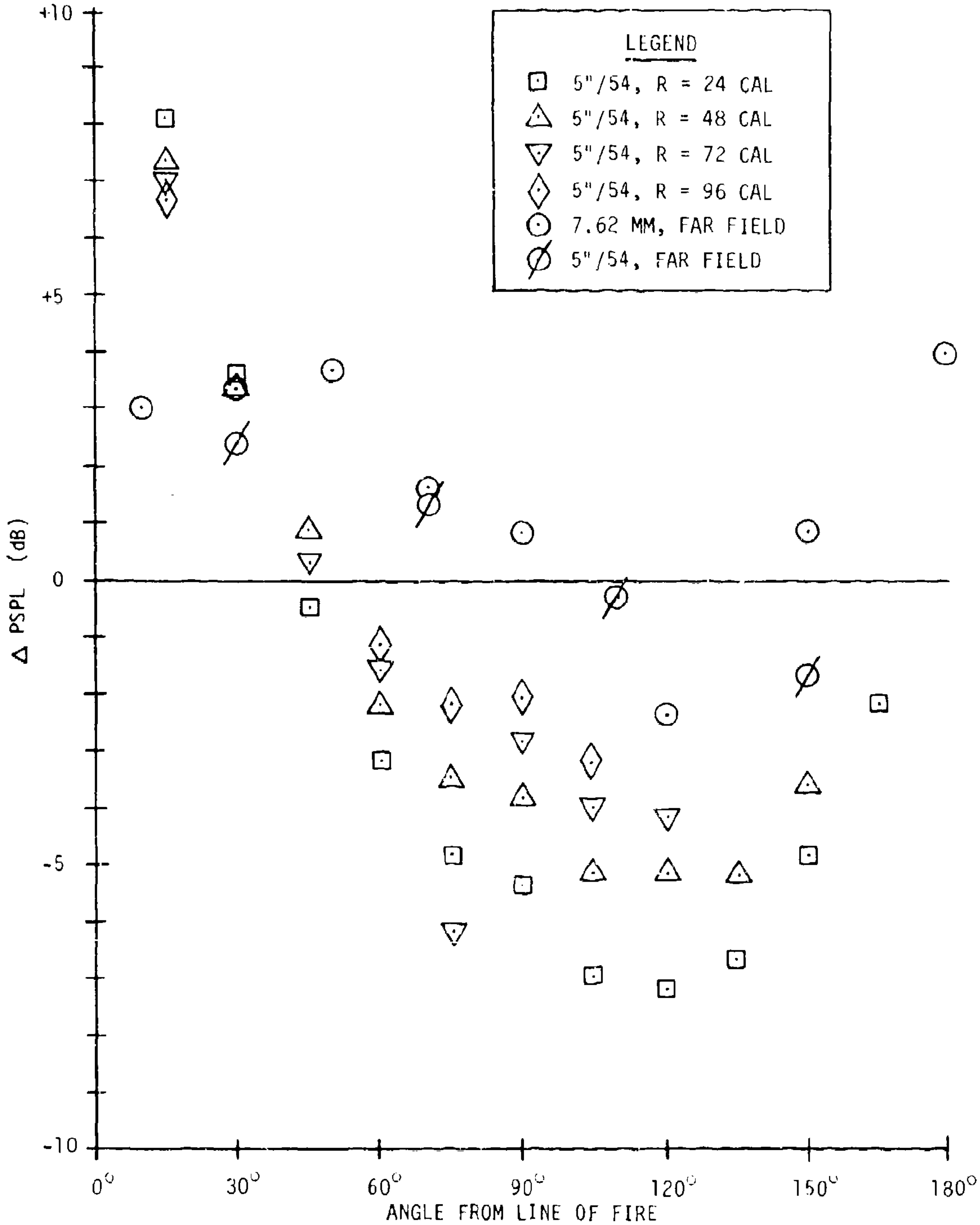

Figure 7. Change in PSPL Due to 10° Conical Muzzle Device

Table 3. 10° Conical Muzzle Device Far-Field PSPL Raw Data, 7.62-mm Rifle Test

Angle from Direction of Fire (degrees)	Peak Sound Pressure Level (dB) @ R (calibers)							
	14,000		26,000		80,200		138,000	
	Bare Muzzle	10° Cone	Bare Muzzle	10° Cone	Bare Muzzle	10° Cone	Bare Muzzle	10° Cone
10	123.2	126.4	117.3	120.1	106.4	109.9	101.3	104.0
30	122.7	126.1	112.5	116.2	109.3	112.6	102.2	105.5
50	122.4	125.8	114.4	118.5	107.2	110.4	100.3	104.4
70	120.0	121.8	113.4	115.1	107.3	108.7	94.6	96.1
90	119.3	119.5	111.8	112.4	103.6	105.2	95.6	96.6
120	115.3	113.6	108.4	107.2	99.8	95.6	91.5	88.9
150	111.2	110.4	105.7	105.1	95.5	97.2	84.2	87.3
180	110.9	114.3	102.0	107.6	95.4	100.2	86.1	87.8

Table 4. Change in Far-Field PSPL Due to 10° Conical Muzzle Device, 7.62-mm Rifle Test

Angle from Direction of Fire (degrees)	Δ PSPL (dB) @ R (calibers)				
	14,000	26,000	80,200	138,000	All (mean)
10	+3.2	+2.8	+3.5	+2.7	+3.0
30	+3.4	+3.7	+3.3	+3.3	+3.4
50	+3.4	+4.1	+3.2	+4.1	+3.7
70	+1.8	+1.7	+1.4	+1.5	+1.6
90	+0.2	+0.6	+1.6	+1.0	+0.8
120	-1.7	-1.2	-4.2	-2.6	-2.4
150	-0.8	-0.6	+1.7	+3.1	+0.8
180	+3.4	+5.6	+4.8	+1.7	+3.9

because they were located in a region of greatly reduced sound level. The resultant data are shown in Table 5 and Figures 7 and 8; each datum in Table 5 is the mean value from up to five test rounds.

The far-field data for the 10° conical muzzle devices exhibited rather large scatter, so that any conclusions must be somewhat tentative. The presentation shown in Figure 7 strongly indicates, however, that the near-field directivity enhancement effect of the conical muzzle device is considerably decreased by the time the blast wave reaches the distances ($R \simeq 10^4 - 10^5$) at which far-field data were measured. Figure 8 illustrates that the change in far-field PSPL due to the

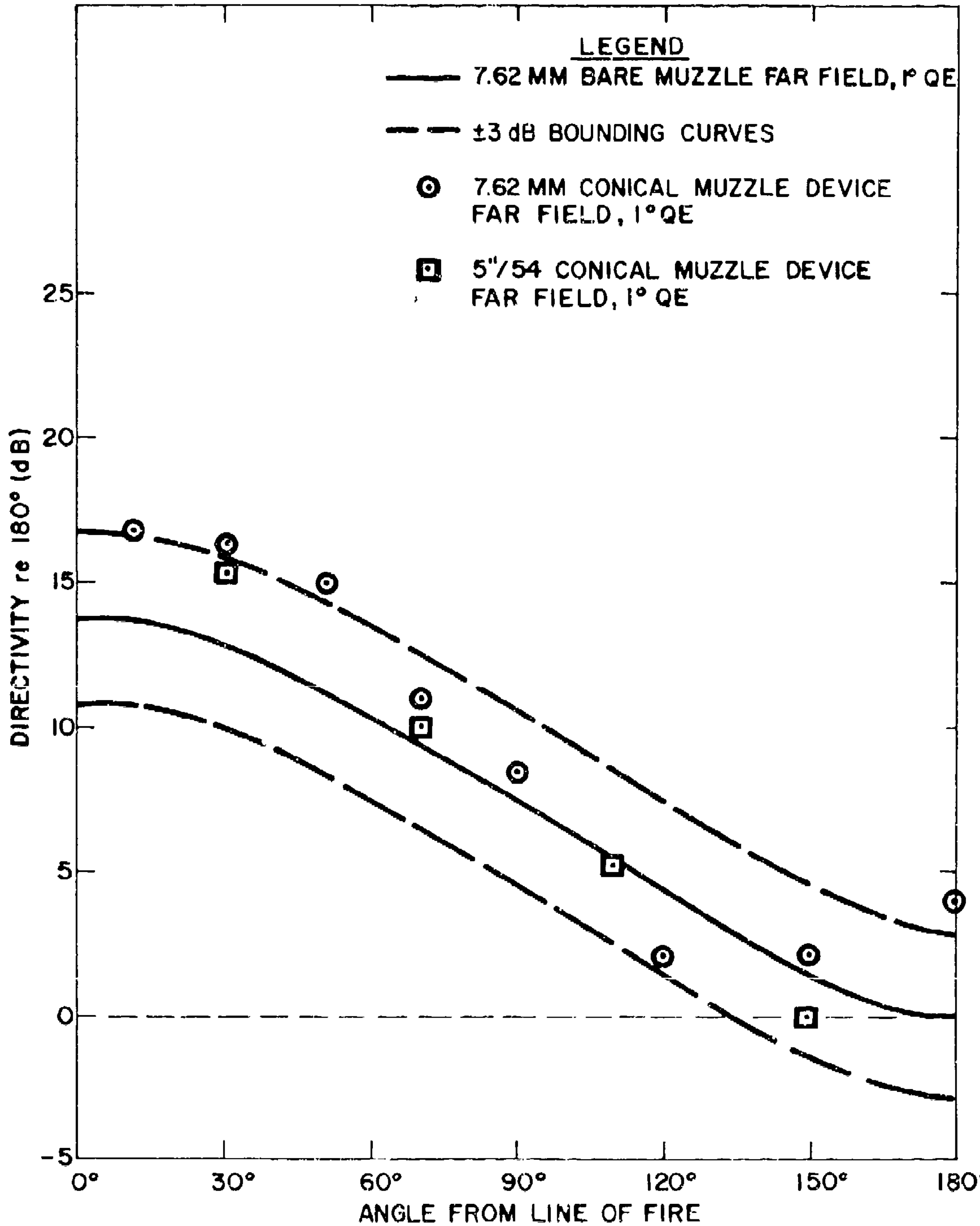

Figure 8. Change in Muzzle Blast Far-Field PSPL Due to 10° Conical Muzzle Device

conical muzzle device is generally smaller than 3 dB, and that even these reductions occur in only a limited portion of the blast field. Such a device may be of use, however, in some scenarios, e.g., at a firing range that can take advantage of bare muzzle directivity and/or needs only a small increment of further noise reduction to meet a noise regulation. It should be kept in mind that a conical muzzle device is generally much lighter in weight than other noise reducing muzzle devices. Also, the noise reduction occurs in a region where projectile bow shock does not exist, while the noise increase occurs in the bow shock region and, thus, may be of lesser significance. Finally, the muzzle device tested in this exploratory development project has not been optimized; it may be possible to achieve increased directivity enhancement. In summary, it appears that conical (or possibly other forms, e.g., paraboloid[27]) muzzle devices are of quite limited utility for noise control, but may find application in special circumstances.

Table 5. Change in Far-Field PSPL Due to 10°
Conical Muzzle Device, 5"/54 Naval Gun Test

Angle from Direction of Fire (degrees)	Δ PSPL (dB) @ R (calibers)			
	25,200	76,300	140,000	All (mean)
30	+2.3	+2.6	___	+2.4
70	+0.6	+2.3	___	+1.4
110	-0.3	___	___	-0.3
150	-1.7	___	___	-1.7

BLAST REDUCER MUZZLE DEVICES

Many silencers have been built and tested,[29,30] including some specifically intended for use on major-caliber guns.[31,32] Reductions in PSPL of more than 20 dB have been achieved, generally by means of long cylindrical canisters with internal baffles. Silencers that yield such dramatic noise level reductions are generally quite large, often of roughly the same length and weight as the gun barrel. These are not suitable for use on major-caliber guns except possibly in special circumstances that would allow the device to be separately supported.

The objective of most previous silencer development programs has been to achieve great reductions in blast overpressure, to the point of inaudibility in the far field. Such dramatic reductions would certainly be very desirable for noise control, but a smaller reduction in far-field noise level could still be useful. The objective of this portion of the current project was to determine the feasibility of a blast reducer muzzle device, i.e., a silencer of moderate effectiveness, that might yield a useful reduction (~10 dB) in noise level and still be small and lightweight enough to be used on existing major-caliber gun systems without requiring additional support and without damaging the gun.

Very little information regarding the performance of such devices is available. An extensive parameter study was planned, using an adjustable blast reducer muzzle device. The tests were carried out at reduced scale using the 7.62-mm rifle apparatus and procedures described earlier. The adjustable blast reducer consisted of a cylindrical tube that was mounted on the gun muzzle and could be fitted with a variety of parts to vary device length, internal volume, and baffle shape, location, and number. The device is shown mounted on the gun in Figure 5.

Only two configurations, designated as BR-A and BR-F, and shown schmatically in Figures 9 and 10, were actually tested. These devices were of a size judged to be at or beyond the limit of practicality for use on existing large guns. Results are shown in Tables 6 through 9 and Figure 11. Configuration BR-A, a cylinder 8 calibers long and 5 calibers in diameter with three curved baffles

NOTE: DIMENSIONS IN CALIBERS

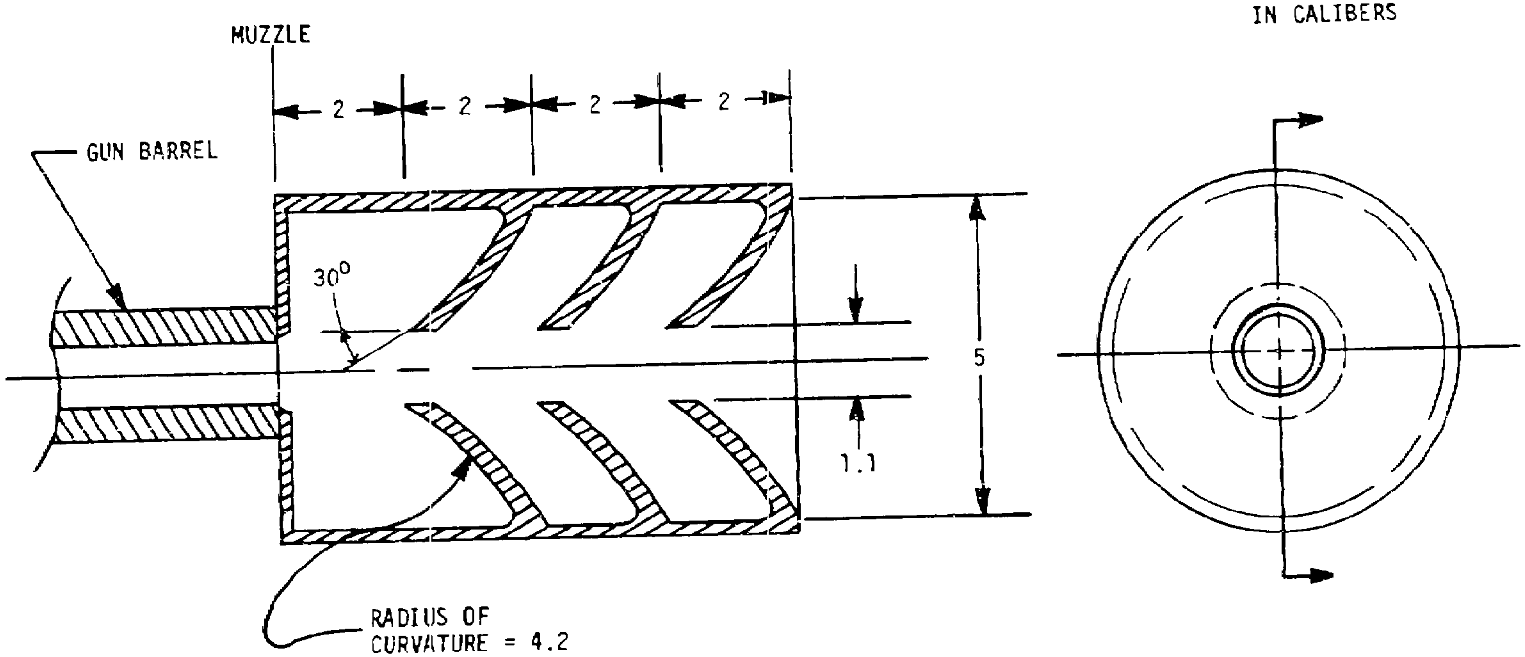

Figure 9. Schematic Cross Section of Blast Reducer Configuration BR-A

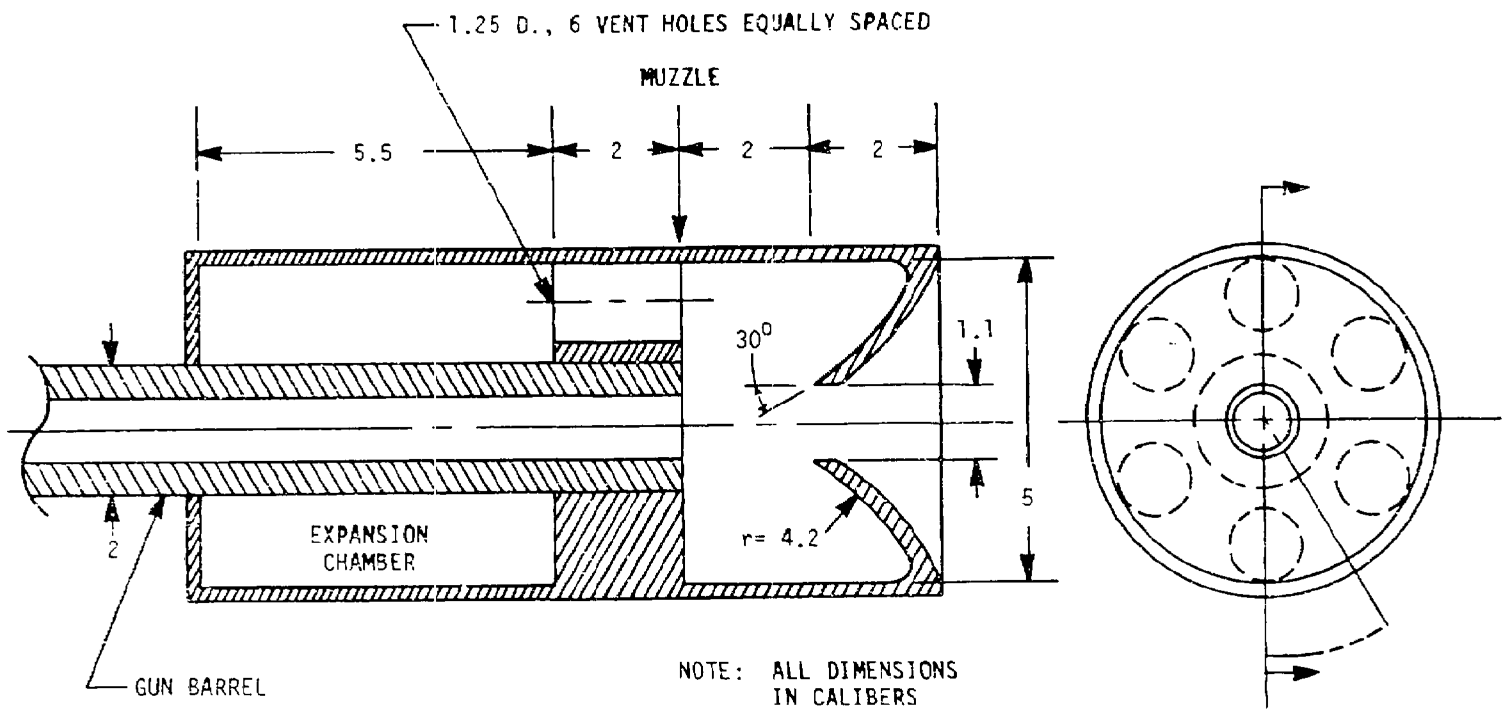

Figure 10. Schematic Cross Section of Blast Reducer Configuration BR-F

Table 6. BR-A Far-Field PSPL Raw Data

Angle from Direction of Fire (degrees)	Peak Sound Pressure Level (dB) @ R (calibers)							
	14,000		26,000		80,200		138,000	
	Bare Muzzle	BR-A	Bare Muzzle	BR-A	Bare Muzzle	BR-A	Bare Muzzle	BR-A
30	122.2	117.1	115.1	110.4	106.5	103.0	96.3	95.0
90	117.8	113.7	111.2	108.2	100.3	98.6	94.0	88.6
150	110.2	109.5	104.1	101.7	89.3	85.3	84.8	75.7

Gun: 7.62-mm rifle

Table 7. Change in Far-Field PSPL Due to Blast Reducer BR-A

Angle from Direction of Fire (degrees)	Δ PSPL (dB) @ R (calibers)				
	14,000	26,000	80,200	138,000	All (mean)
30	-5.1	-4.7	-3.5	-1.3	-3.6
90	-4.1	-3.0	-1.7	-5.4	-3.6
150	-0.7	-2.4	-4.0	-9.1	-4.0

spaced at 2 caliber intervals, yielded a PSPL reduction of ~4 dB. Configuration BR-F, a single curved baffle design with an expansion chamber, yielded ~5 dB reduction in PSPL. Reductions of these magnitudes probably do not justify use of such large, heavy muzzle devices.

WATER SPRAY

An interesting concept for gun blast noise reduction is to introduce some substance into the muzzle region that could interact with and remove energy from the blast wave. It would be desirable for this substance to be cheap, easily handled, and of minimal environmental impact. A substance that comes immediately to mind is water. The total energy released by the propellant of a 5"/54 naval gun is on the order of 5×10^6 ft-lb (1.6×10^6 cal), which is equivalent to the heat of vaporization of a few liters of water. Actually, less than half of the propellant energy goes into the blast wave.[33] A difficulty is that the time available for the energy interaction to occur is very short.

Table 8. BR-F Far-Field PSPL Raw Data

Angle from Direction of Fire (degrees)	Peak Sound Pressure Level (dB) @ R (calibers)							
	14,000		26,000		80,000		138,000	
	Bare Muzzle	BR-F	Bare Muzzle	BR-F	Bare Muzzle	BR-F	Bare Muzzle	BR-F
30	122.9	121.6	115.1	114.0	108.3	107.8	101.8	99.9
90	120.2	116.7	114.1	110.8	104.1	96.9	95.7	89.0
150	111.8	107.4	106.8	102.6	98.7	90.1	85.0	79.5

Gun: 7.62-mm rifle

Table 9. Change in Far-Field PSPL Due to Blast Reducer BR-F

Angle from Direction of Fire (degrees)	Δ PSPL (dB) @ R (calibers)				
	14,000	26,000	80,200	138,000	All (mean)
30	-1.3	-1.1	-0.5	-1.9	-1.2
90	-3.5	-3.3	-7.2	-6.7	-5.2
150	-4.4	-4.2	-8.6	-5.5	-5.7

A preliminary feasibility investigation was conducted to determine if significant noise reductions could be readily achieved by means of water spray. Two series of exploratory experiments were performed, using the 7.62-mm rifle and a 40-mm naval gun, respectively. Water spray was provided for both tests by fire department equipment, specifically a "Grant Gun" equipped with a "Fog Hog" nozzle, with water supplied from a hydrant by means of a pumper truck and 3-inch diameter fire hose; flow rates were on the order of hundreds of gallons per minute. The nozzle was adjusted to give the finest spray (smallest droplet size) attainable; no other control or measurement of droplet size was attempted. The water spray obtained appeared to be a fine, dense mist, i.e., the droplet size appeared to be quite small by ordinary standards, although they were very probably much larger than micron-size. The spray was directed at about 90° to the line of fire, from a point to one side of the muzzle that resulted in the muzzle region being engulfed by fine, dense mist, as shown in Figure 12. The mist was so fine as to be greatly affected by even moderate wind.

The 7.62-mm rifle experiment used the rifles discussed earlier, shown in Figures 5 and 12. The gun muzzles were covered by a small piece of tape to prevent water entry. The firing procedure was to first establish suitable water

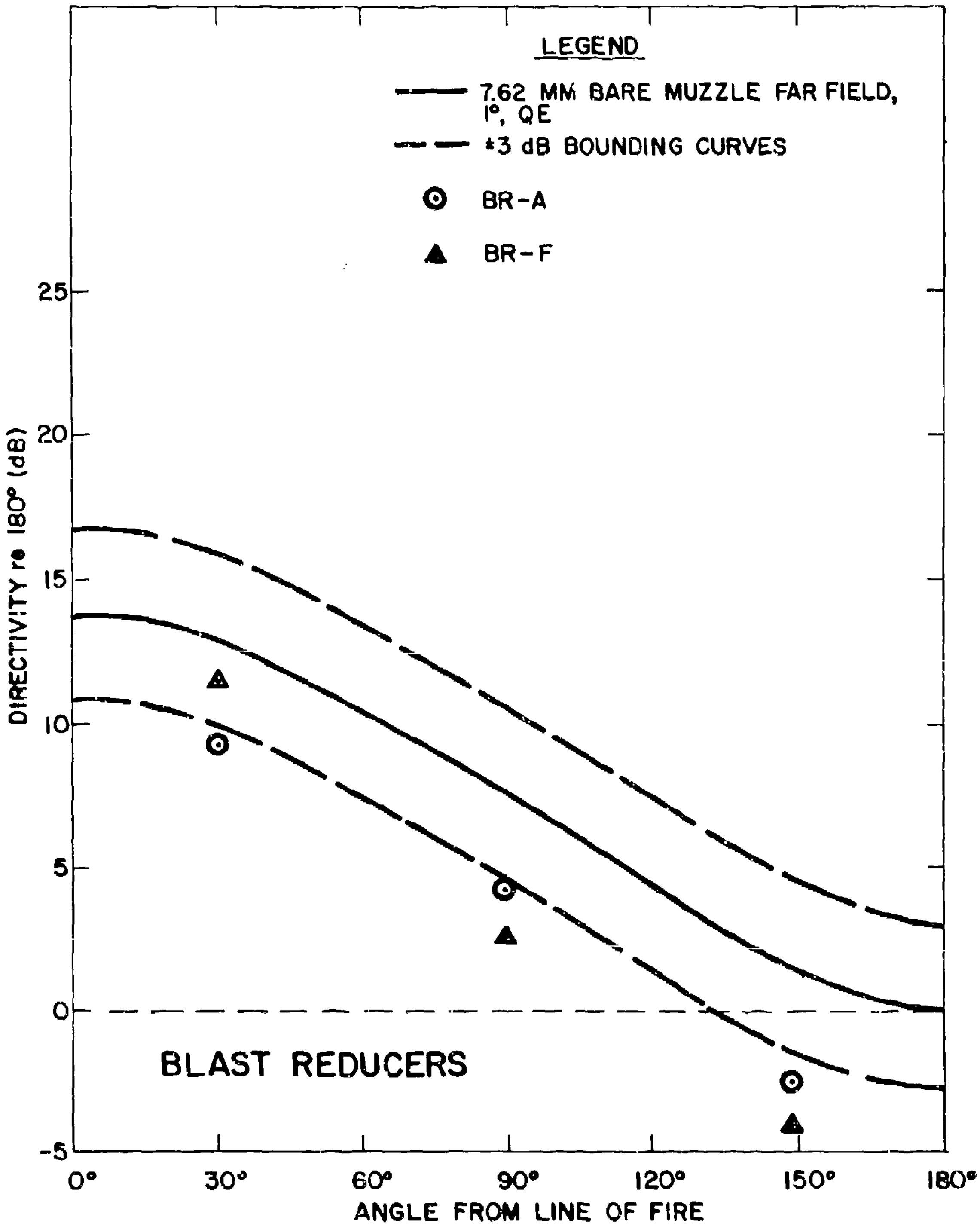

Figure 11. Change in Muzzle Blast Far-Field PSPL
Due to Blast Reducer Muzzle Devices

Figure 12. Water Spray

spray, fire the lower gun, turn off the water spray, and finally fire the upper (baseline) gun; elapsed time between firing of the two guns was about 10 to 12 seconds. Instrumentation consisted of six Gen Rad Model 1982 sound level meters and the automated data recording system described earlier. Instrumentation field locations were at 45, 90, and 135° to either side of the line of fire, at a radial distance of 4,000 calibers from the gun muzzle. Projectile bow shock was eliminated from the blast field by means of a bullet trap.

Results of the 7.62-mm water spray experiment are shown in Table 10. The average reduction in PSPL due to the water spray was only 1.6 dB, a reduction large enough to be interesting but not large enough to be useful.

Another water spray experiment was performed using a fairly large gun, the 40-mm naval gun. Far-field instrumentation and data acquisition apparatus was similar to that for the 7.62-mm rifle, except that only four Gen Rad 1982 sound level meters were used, located 90 and 135° to either side of the line of fire at a radial distance from the muzzle of 1,143 calibers. Near-field overpressure was also measured by means of two Ostronics Model PB-200 pencil-type blast gages pointed at the muzzle and located at 45° right, 66 calibers and 105° right, 55 calibers; data was recorded onto a Honeywell Model 5600 tape recorder.

The gun was a standard 40-mm naval gun with the conical "flash hider" muzzle device removed and was fired at an elevation angle of approximately 0°. The muzzle was covered with 4-mil plastic film to prevent water entry. Ammunition consisted of standard service propelling charges and Mk 2 inert projectiles. No attempt was made to stop the projectile to eliminate projectile bow shock from the blast field; no measurements were made in the bow shock region of the far field, and the bow shock PSPL is much smaller than the muzzle blast PSPL in the near field. The water spray in all cases was directed at $\simeq 90°$ to the line of fire, with the spray apparatus located at various positions as required, for various spray nozzle adjustments, such that the gun muzzle was engulfed in the fine mist portion of the spray pattern. Flow rate throughout the test was approximately 600 gallons/minute. Because the gun had to be reloaded before each shot, elapsed time between water spray and bare muzzle shots varied from 40 to 120 seconds.

Table 10. 7.62-mm Rifle Water Spray Experiment

Rd. No.	Parameter	PSPL (dB) @ R = 4000 calibers, Angle from Line of Fire (degrees) =						Mean Δ PSPL (dB)
		45 right	90 right	135 right	135 left	90 left	45 left	
1	Water Spray, 370 GPM	142.8	127.9	125.8	126.2	127.7	133.9	
2	Bare Muzzle	142.2	132.5	128.8	126.6	129.3	133.7	
1,2	Δ PSPL	+0.6	-4.6	-3.0	-0.4	-1.6	+0.2	-1.5
3	Water Spray, 370 GPM	142.5	129.1	124.5	125.6	128.0	134.0	
4	Bare muzzle	146.9	133.6	128.6	130.7	130.0	135.6	
3,4	Δ PSPL	-4.4	-4.5	-4.1	-5.1	-2.0	-1.6	-3.6
5	Water Spray, 370 GPM	147.2	130.1	125.1	126.1	127.7	135.6	
6	Bare Muzzle	140.9	132.8	129.4	127.1	129.7	137.2	
5,6	Δ PSPL	+6.3	-2.7	-4.3	-1.0	-2.0	-1.6	-0.9
7	Water Spray, 500 GPM	145.5	128.2	128.5	128.5	128.9	133.9	
8	Bare Muzzle	145.5	129.6	126.6	129.2	130.3	134.7	
7,8	Δ PSPL	0.0	-1.4	+1.9	-0.7	-1.4	-0.8	-0.4
All	Mean Δ PSPL	+0.6	-3.3	-2.4	-1.8	-1.8	-1.0	$\boxed{-1.6}$

Note: Wind during test ~5 kn, from 135° left to 45° right.

The results of the experiment are shown in Table 11. The overall average, for near-field and far-field data, of the change in PSPL due to the water spray was -2.5 dB. The far-field data exhibited considerable scatter, but on the average the PSPL values for near field and far field agreed fairly well. Spray configuration seemed to have little effect on change in PSPL as long as the gun muzzle was engulfed in the fine mist region of the spray (spray configurations B, C, and D); for these cases the PSPL reduction was about 3 dB, compared to about 1.5 dB for spray configuration A (muzzle engulfed in the high-velocity jet region of the spray pattern).

The PSPL reduction of about 3 dB that was obtained is of little utility for noise control except possibly under special circumstances.* The reduction is, however, large enough to be interesting, and perhaps merits further investigation (no further investigation was undertaken during the current project).

It is difficult to speculate on what changes should be made to the water spray characteristics, since the phenomenological mechanism that produced the PSPL reduction is not known. It seems plausible that a dense concentration of much smaller droplets might be required, which would make the mist even more susceptible to disruption by wind.

FOAM

Recent experiments[34,35] have shown that foam can yield large reductions in airblast PSPL from explosive charge detonations. In these experiments, the explosive charge was engulfed in aqueous foam such as is used in firefighting. A preliminary investigation into the utility of foam for reducing gun muzzle blast noise was carried out as part of the present project.

The foam that was used in this initial investigation was shaving cream, contained in a small (diameter $\simeq$20 calibers) plastic bag taped to the muzzle of the

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* See "CONICAL MUZZLE DEVICE" section for further discussion.

Table 11. 40-mm Gun Water Spray Experiment

Round Number (BM = Bare Muzzle	Spray* Configuration	PSPL (dB) @ R (calibers), θ (degrees) =						Mean Δ PSPL (dB)
		1143, 90 right	1143, 135 right	1143, 135 left	1143, 90 left	66, 45 right	55, 105 right	
1 (Spray)	A	151.4	134.4	136.3	145.7	176.8	169.1	
2 (BM)		145.5	135.3	137.0	147.8	NO DATA	NO DATA	
1-2, Δ PSPL		+5.9	-0.9	-0.7	-2.1	NO DATA	NO DATA	+0.6
3 (Spray)	A	149.6	135.2	137.8	145.3	175.7	168.8	
4 (BM)		148.1	136.9	144.8	148.4	178.4	173.5	
3-4, Δ PSPL		+1.5	-1.7	-7.0	-3.1	-2.7	-4.7	-3.0
5 (Spray)	A	150.7	135.7	141.6	147.9	175.8	168.8	
6 (BM)		156.5	137.7	141.2	148.8	NO DATA	173.4	
5-6, Δ PSPL		-5.8	-2.0	+0.4	-0.9	NO DATA	-4.6	-2.6
7 (Spray)	A	153.1	135.9	141.2	147.6	177.3	169.6	
8 (BM)		143.9	135.6	138.5	148.7	179.2	173.4	
7-8, Δ PSPL		+9.2	+0.3	+2.7	-1.1	-1.9	-3.8	+0.9

* Spray Configuration A: Spray nozzle location 6 cal forward, 11 cal right, spray angle setting 90°, water flow rate ~600 GPM.

Table 11. 40-mm Gun Water Spray Experiment (Cont'd)

Round Number (BM = Bare Muzzle	Spray* Configuration	PSPL (dB) @ R (calibers), θ (degrees) =						Mean Δ PSPL (dB)
		1143, 90 right	1143, 135 right	1143, 135 left	1143, 90 left	66, 45 right	55, 105 right	
9 (Spray)	A	147.1	132.0	140.8	146.9	178.2	168.8	
10 (BM)		149.6	136.1	140.1	148.3	179.0	173.5	
9-10, Δ PSPL		-2.5	-4.1	+0.7	-1.4	-0.8	-4.7	-2.1
1-10, Mean Δ PSPL	A	+1.7	-1.7	-0.8	-1.7	-1.8	-4.4	$\boxed{-1.4}$
11 (Spray)	B	149.9	137.3	140.0	141.4	176.6	170.5	
12 (BM)		151.1	137.9	142.7	149.0	179.8	174.7	
11-12, Δ PSPL		-1.2	-0.6	-2.7	-7.6	-3.2	-4.2	-3.2
13 (Spray)	B	143.8	136.7	139.9	143.9	176.6	171.6	
14 (BM)		152.4	138.5	140.4	148.1	179.8	174.7	
13-14, Δ PSPL		-8.6	-1.8	-0.5	-4.2	-3.2	-3.1	-3.6

* Spray Configuration B: Spray nozzle location 16 cal forward, 77 cal right, spray angle setting 90°, water flow rate ~600 GPM.

Table 11. 40-mm Gun Water Spray Experiment (Cont'd)

Round Number (BM = Bare Muzzle	Spray* Configuration	PSPL (dB) @ R (calibers), θ (degrees) =						Mean Δ PSPL (dB)
		1143, 90 right	1143, 135 right	1143, 135 left	1143, 90 left	66, 45 right	55, 105 right	
15 (Spray)	B	153.2	138.0	138.0	143.0	177.1	171.6	
16 (BM)		155.3	138.9	141.3	149.2	180.5	174.0	
15-16, Δ PSPL		-2.1	-0.9	-3.3	-6.2	-3.4	-2.4	-3.0
11-16, Mean Δ PSPL	B	-4.0	-1.1	-2.2	-6.0	-3.3	-3.2	$\boxed{-3.3}$
17 (Spray)	C	152.5	135.8	138.8	140.3	177.7	171.3	
18 (BM)		156.5	137.0	141.1	147.4	180.5	173.5	
17-18, Δ PSPL		-4.0	-1.2	-2.3	-7.1	-2.8	-2.2	-3.3
19 (Spray)	C	151.9	135.1	140.2	141.0	178.5	171.2	
20 (BM)		154.6	139.4	143.0	146.0	180.0	174.6	
19-20, Δ PSPL		-2.7	-4.3	-2.8	-5.0	-1.5	-3.4	-3.3

* Spray Configuration C: Spray nozzle location 11 cal forward, 77 cal right, spray angle setting 60°, water flow rate ~600 GPM.

Table 11. 40-mm Gun Water Spray Experiment (Cont'd)

Round Number (BM = Bare Muzzle	Spray* Configuration	PSPL (d3) @ R (calibers), θ (degrees) =						Mean Δ PSPL (dB)
		1143, 90 right	1143, 135 right	1143, 135 left	1143, 90 left	66, 45 right	55, 105 right	
21 (Spray)	C	154.2	139.4	138.1	141.4	177.8	171.3	
22 (BM)		154.4	137.5	139.4	148.5	180.8	174.5	
21-22, Δ PSPL		-0.2	+1.9	-1.3	-7.1	-3.0	-3.2	-2.2
17-22, Mean Δ PSPL	C	-2.3	-1.2	-2.1	-6.4	-2.4	-2.9	$\boxed{-2.9}$
23 (Spray)	D	153.9	135.9	138.7	147.7	178.4	168.9	
24 (BM)		156.0	140.2	140.0	147.3	NO DATA	NO DATA	
23-24, Δ PSPL		-2.1	-4.3	-1.3	+0.4	NO DATA	NO DATA	-1.8
25 (Spray)	D	154.5	132.8	136.6	143.1	NO DATA	NO DATA	
26 (BM)		154.3	141.5	141.2	148.4	NO DATA	NO DATA	
25-26, Δ PSPL		+0.2	-8.7	-4.6	-5.3	NO DATA	NO DATA	-4.6

* Spray Configuration D: Spray nozzle location 10 cal forward, 77 cal right, spray angle setting 30°, water flow rate ~600 GPM.

Table 11. 40-mm Gun Water Spray Experiment (Cont'd)

Round Number (BM = Bare Muzzle	Spray* Configuration	PSPL (dB) @ R (calibers), θ (degrees) =						Mean Δ PSPL (dB)
		1143, 90 right	1143, 135 right	1143, 135 left	1143, 90 left	66, 45 right	55, 1C5 right	
27 (Spray)	D	154.8	135.5	137.7	142.8	NO DATA	NO DATA	
28 (BM)		155.1	139.9	142.8	146.8	NO DATA	NO DATA	
27-28, Δ PSPL		-0.3	-4.4	-5.1	-4.0	NO DATA	NO DATA	-3.4
23-28, Mean Δ PSPL	D	-0.7	-5.8	-3.7	-3.0	NO DATA	NO DATA	-3.3
1-28, Mean Δ PSPL	ALL	-0.9	-2.3	-2.0	-3.9	-2.5	-3.6	-2.5

* Spray configuration D: Spray nozzle location 10 cal forward, 77 cal right, spray angle setting 30°, water flow rate ~600 GPM.

Note: Wind during test 0 to 10 kn variable, from 90 to 135 left variable.

7.62-mm rifle, with the gun muzzle located approximately at the center of the foam mass. A small piece of tape over the muzzle was used, as a safety precaution, to prevent entry of foam into the gun barrel. Apparatus and procedures were similar to those discussed earlier; data was obtained only at 90° from the line of fire. Resultant data is shown in Table 12.

The foam produced about a 10-dB decrease in muzzle blast PSPL. The data clearly shows that the effect was not due to the tape over the muzzle or the presence of the plastic bag. These results were extremely encouraging, especially in light of the small reductions obtained by other techniques, and motivated an expanded investigation. Results of that investigation are reported under separate cover.[36,37]

SUMMARY OF CONCLUSIONS

1. Muzzle brakes yield a small decrease in noise level in front of the gun (in the projectile bow shock region) and a fairly significant increase behind the gun and, hence, are not expected to be useful for gun blast noise reduction/redistribution.

2. Blast focusing muzzle devices yield small increases in noise level in front of the gun and small decreases behind. Such devices, being relatively lightweight, may be of limited use for noise control under special circumstances.

3. Blast reducing muzzle devices (silencers) that yield large noise level reductions are very heavy; those that are light enough to be used on existing large guns yield insignificant noise level reductions.

4. A preliminary (and somewhat cursory) investigation of the feasibility of using water spray to reduce gun blast noise levels yielded only small (~3 dB) reductions in PSPL. The water mist was quite susceptible to disruption by wind.

5. A limited preliminary investigation of the use of foam to reduce gun blast noise was quite encouraging; a 10-dB drop in muzzle blast PSPL was obtained on the first try. Further investigation is reported under separate cover.[37]

Table 12. 7.62-mm Gun Foam Experiment

Round Number, Muzzle Configuration (BM = Bare Muzzle)	PSPL (dB) @ 90° from Line of Fire, R (calibers) =				Mean Δ PSPL (dB)
	14,000	26,000	80,200	138,000	
1, Tape over muzzle	117.9	109.6	95.6	88.7	
2, BM	117.8	105.1	97.2	95.2	
1-2, Δ PSPL	+0.1	+4.5	-1.6	-6.5	-0.9
3, Tape	117.7	111.3	96.8	90.8	
4, BM	117.8	105.6	100.8	93.9	
3-4, Δ PSPL	-0.1	+5.7	-4.0	-3.1	-0.4
5, Tape	117.4	108.7	100.3	89.4	
6, BM	116.1	108.6	97.2	97.5	
5-6, Δ PSPL	+1.3	+0.1	+3.1	-8.1	-0.9
7, Tape	117.9	110.5	103.6	96.4	
8, BM	117.3	110.1	99.8	91.9	
7-8, Δ PSPL	+0.6	+0.4	+3.8	+4.5	+2.3

Table 12. 7.62-mm Gun Foam Experiment (Cont'd)

Round Number, Muzzle Configuration (BM = Bare Muzzle)	PSPL (dB) @ 90° from Line of Fire, R (calibers) =				Mean Δ PSPL (dB)
	14,000	26,000	80,200	138,000	
9, Tape	117.4	110.6	100.7	91.4	
10, BM	118.0	112.1	100.5	100.6	
9-10, Δ PSPL	-0.6	-1.5	+0.2	-9.2	-2.8
1-10, Mean Δ PSPL (Effect of Tape)	+0.3	+1.8	+0.3	-4.5	$\boxed{-0.5}$
11, Tape + Empty Bag	118.3	112.3	101.1	88.6	
12, BM	117.7	110.1	100.3	99.3	
11-12, Δ PSPL	+0.6	+2.2	+0.8	-10.7	-1.8
13, Tape + Empty Bag	116.8	109.4	103.7	98.0	
14, BM	118.9	111.4	103.2	98.3	
13-14, Δ PSPL	-2.1	-2.0	+0.5	-0.3	-1.0

Table 12. 7.62-mm Gun Foam Experiment (Cont'd)

Round Number, Muzzle Configuration (BM = Bare Muzzle)	PSPL (dB) @ 90° from Line of Fire, R (calibers) =				Mean Δ PSPL (dB)
	14,000	26,000	80,200	138,000	
15, Tape + Empty Bag	118.1	109.5	105.6	100.0	
16, BM	118.6	111.2	102.4	88.7	
15-16, Δ PSPL	-0.5	-1.7	+3.2	+11.3	+3.1
11-16, Mean Δ PSPL (Effect of Tape + Empty Bag)	-0.7	-0.5	+1.5	+0.1	$\boxed{+0.1}$
17, Foam*	107.2	101.4	84.9	89.2	
18, BM	118.6	111.9	97.4	98.0	
17-18, Δ PSPL	-11.4	-10.5	-12.5	-8.8	-10.8
19, Foam*	111.4	105.9	92.3	85.6	
20, BM	116.6	106.4	97.2	94.6	
19-20, Δ PSPL	-5.2	-0.5	-4.9	-9.0	-4.9

* Foam was contents of one 11 oz pressurized can of commercial shaving cream.

Table 12. 7.62-mm Gun Foam Experiment (Cont'd)

Round Number, Muzzle Configuration (BM = Bare Muzzle)	PSPL (dB) @ 90° from Line of Fire, R (calibers) =				Mean Δ PSPL (dB)
	14,000	26,000	80,200	138,000	
21, Foam*	107.5	103.9	85.9	79.4	
22, BM	117.8	111.2	99.3	91.5	
21-22, Δ PSPL	-10.3	-7.3	-13.4	-12.1	-10.8
17-22, Mean Δ PSPL (Effect of Foam)	-9.0	-6.1	-10.3	-10.1	$\boxed{-8.8}$

* Foam was contents of one 11 oz pressurized can of commercial shaving cream.

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